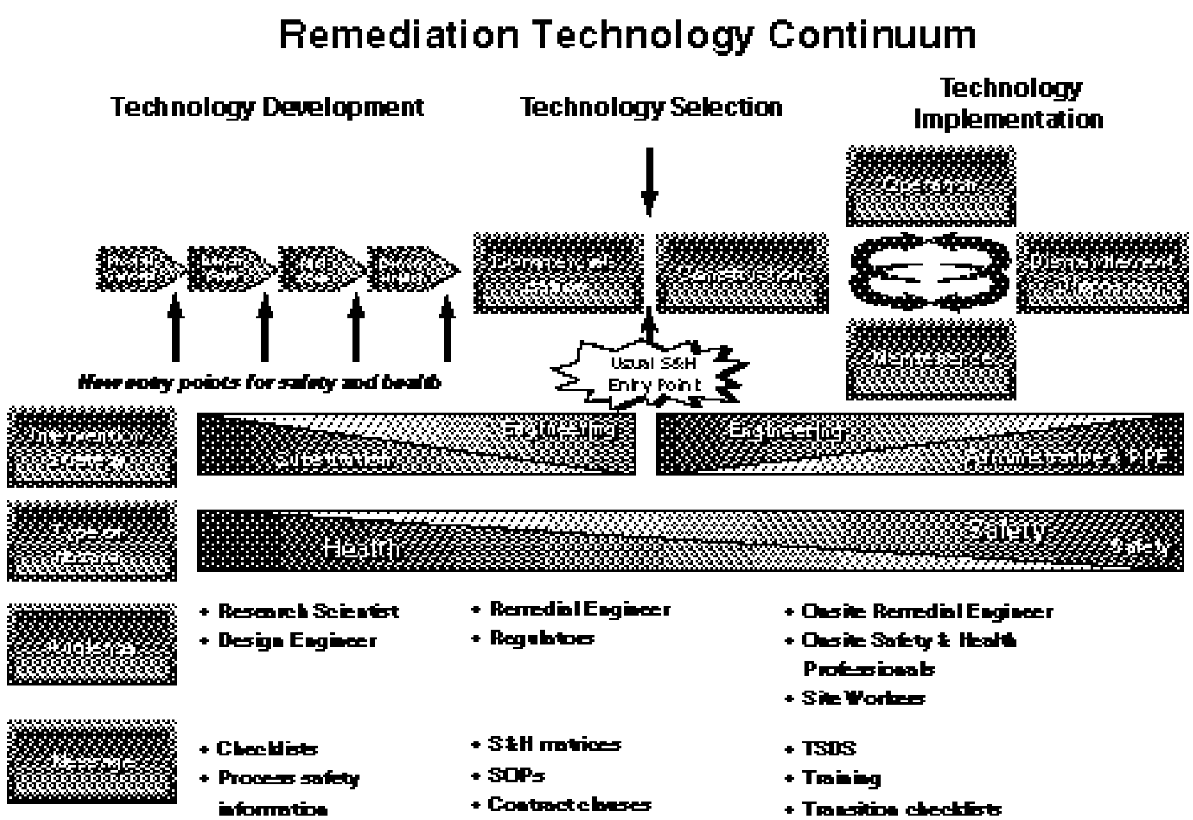
INTRODUCTION

Injecting Safety and Health Considerations Into the Technology Life-Cycle Continuum

In considering the life cycle of an environmental remediation technology — from idea through research and development, testing, implementation, operation, decommissioning, and dismantlement — it is clear that many opportunities exist to inject safety and health considerations into the technology life-cycle continuum (see illustration below). By recognizing risks as early as possible in the development and testing process, technologies that prove to be commercially viable can be constructed, operated, maintained, and dismantled with a minimum of health and safety hazards to workers at acceptable costs.



The technology continuum, highlighting new entry points.

To accomplish this objective, a process is needed to systematically identify and remove, wherever possible, safety and health hazards from environmental remediation technologies. This document is intended to provide guidance to people interested in contributing to the development of such a process that can be applied across a broad spectrum of technologies. Innovative strategies for hazard communication are also an important focus. Where hazards cannot be avoided in the research and development phase of an emerging technology, the goal is to reduce the safety and health hazards as much as practicable. The residual health and safety risks then must be communicated to field personnel actually using the technologies and performing the cleanup activities.

The protocols developed in the course of defining this process will be useful to research scientists, design engineers, site remediation engineers, safety professionals and, ultimately and perhaps most importantly, to workers. These groups or audiences have different perspectives and needs.

Research Scientists and Design Engineers: Because these individuals can influence the nature of a technology from the initial concept all the way through to demonstration, they are well positioned to mitigate its associated hazards. Such individuals must be encouraged to anticipate and consider hazards that may be new to them and to actively look for hazards in practical applications that were unforeseen in the conceptual stage.

Remedial Design Engineers: These engineers are responsible for selecting which technology will be used to clean up a particular site. Documentation aimed at these individuals will allow them to easily compare one technology with another in terms of safety and health hazards, and will be developed from the guidance supplied to senior safety professionals.

Senior Safety Professionals: These individuals have an in-depth understanding of safety and health hazards and the skill to identify them. The documentation aimed at these professionals includes protocols for hazard identification, which are intended to enhance their already advanced identification skills and to ensure thoroughness in the process. In addition, several vehicles are presented for conveying hazard information downstream, including safety and health hazard matrices, hazard rating scales, checklists for transitions from one stage of operation to another, and Technology Safety Data Sheets (TSDSs).

Onsite Safety Professionals and Workers: These individuals will benefit from strategies that outline how to effectively use hazard information in terms of informational programs, training programs, new-technology programs, planning, and document use. Onsite personnel also are closely involved in pre-incident planning and emergency response.

Background

Promulgation of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 1980 created an impetus for development of new technologies to treat soil, surface water, groundwater, and air emissions contaminated with hazardous materials. As the demand continues for cleanup technologies that are better designed than existing ones as well as being faster and cheaper to operate, new developments continue to evolve. However, though these new technologies receive close scrutiny as they move from the bench-scale stage through pilot testing and into actual operation, little attention has been given to the hazards they might pose to worker health and safety. The databases on environmental remediation technologies maintained by government agencies, such as the Environmental Protection Agency (EPA), the Department of Energy (DOE), and the Air Force, reveal the virtual absence of information regarding safety and health hazards that might be associated with new and emerging technologies. This is because health and safety considerations seldom are included in assessments of these technologies. For example, in an environmental technology review document prepared by DOE's Office of Technology Development[1] in October 1993, only a handful of references to worker safety are made.

Remembering the Worker

In defining ways to inject health and safety considerations into the process of developing innovative cleanup technologies, a key strategy is to remember the worker when health and safety risks finally become the focus of attention. Far too often, even when the focus is brought to bear on health and safety, the risks addressed are those faced by the public, such as contaminated drinking water from a hazardous waste site. Remediation documents often refer to "risks to the public and to workers," but this combined reference tends to downplay the real risks that workers face cleaning up hazardous waste sites — risks that are significantly greater than those faced by the public.

It follows, then, that those charged with making decisions about environmental cleanup technologies must ask what the risk is to the worker. Furthermore, they

[1] FY 1993 Program Summary, Office of Demonstration, Testing, and Evaluation, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, p.10, October 1993.

must be careful not to become so preoccupied with eliminating even the most insignificant environmental health risks to the public that they ignore or underappreciate occupational health practices that pose significant risks to workers.

Emerging environmental remediation technologies are developed in a well-defined procedure that begins with an idea, moves through proof of concept, laboratory trials, bench-scale analysis, and then on to a pilot demonstration. If proven successful in this multistage and rigorous process, a technology can be primed for commercialization. It is during this stage that the ultimate effectiveness of a technology must be demonstrated to compete in the marketplace.

Once it is available on the market, a technology may be selected and implemented to perform a site remediation operation. Many considerations go into selecting a remediation technology, including effectiveness, operating costs, maintenance requirements, production capacity, dependability, and acceptability to the surrounding population. To date, little information has been developed regarding the safety and health hazards associated with remediation technologies. Consequently, engineers tasked with technology selection often do not consider the safety and health implications of their decisions. This can be a costly mistake because of the costs associated with the use of personal protective equipment (PPE), operator training, and the planning required to ensure the safe operation of potentially hazardous cleanup technologies.

The next phase in the technology continuum is selection of a technology for use at a specific site. The technology moves through four distinct stages in this phase, cycling in and out of two of them. As the figure on the first page of this section illustrates, the first stage is construction, the second is operation, the third entails cycling from maintenance to operation and back again, and the fourth is dismantlement and disposition.

The usual entry point of safety and health professionals into the technology development/implementation continuum is after the remediation technology has been selected. As the technology moves through the continuum, several important parameters change.

First, the types of hazards that can be addressed become more limited. Hazards to human health are associated with exposure to certain chemicals, biological agents, and/or physical stressors — hazards that are more successfully addressed in the early design stages of a technology's development when substitution of hazardous chemicals or agents can be made and tested. Hazards to safety, on the other hand, usually are identified later, for example, somewhere between the demonstration stage and commercialization. There are, of course, exceptions to every rule and it is important to consider potential safety hazards early and health hazards late in the process, with an eye toward eliminating all potential hazards.

Just as the types of occupational hazard that can be addressed change over the course of technology development, so does the type of intervention strategy that can be employed. The classic safety approach dictates that controls be used in the following hierarchical order: substitution, engineering control, administrative control and — if, and only if, all other strategies fail or are impractical — PPE. In the early stages of technology development, substitution is a workable control. The research scientist or design engineer can experiment with substituting chemical and physical agents that are less hazardous than those originally planned. As the basic chemical processes that define the chemical treatment process are further defined, however, substitution becomes less of an option.

If substitutions for hazardous chemicals and physical stressors cannot be made, potential exposure scenarios should be engineered out of the remediation technology. This intervention strategy is most applicable during the demonstration and commercialization stages. As a technology is implemented onsite, engineering controls become the predominant intervention strategy. In the late stages of implementation — operation and maintenance — administrative controls and the use of PPE predominate.

Types of Remediation Technologies

Hundreds of remediation technologies currently are in use. Each involves a distinct process and poses its own set of occupational hazards. The technologies can be grouped by the type of environmental media they treat: groundwater, soil vapor, soil, debris, and buildings. An overview of each group of technologies is presented below.

Technologies for Treating Contaminated Groundwater

Volatile Organic Compounds and Fuels

The most commonly used treatment technologies for volatile organic compounds (VOCs) in groundwater and surface water include carbon adsorption and ultraviolet (UV) oxidation. *In situ* treatment technologies are not widely used. Groundwater and surface water concentrations of contaminants usually are not sufficiently high to support biological processes.

Liquid phase **carbon adsorption** is a technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants are absorbed. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place, removed and regenerated at an offsite facility, or removed and disposed of. Carbon used for explosives- or metals-contaminated groundwater must be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewaters by the addition of strong oxidizers and irradiation with intense UV light. The oxidation reactions are catalyzed by UV light, while ozone and/or hydrogen peroxide are commonly used as oxidizing agents. The final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that organic contaminants can be converted to relatively harmless carbon dioxide and water during the process. UV oxidation processes can be configured in batch or continuous-flow modes. Catalyst addition may enhance the performance of the system.

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. The packed tower includes a spray nozzle at the top to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes automated control systems with sump-level switches and safety features such as differential pressure monitors, high sump-level switches and explosion-proof components, and discharge air treatment systems such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed-tower air strippers are installed either as permanent installations on concrete pads, on a skid, or on a trailer.

For **free-product recovery,** undissolved liquid-phase organics are removed from subsurface formations, either by active methods (e.g., pumping) or a passive collection system. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, reused directly in an operation not requiring high-purity materials, or purified prior to reuse. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water (i.e., dual pump or dual well systems).

Inorganic Chemicals

Precipitation, filtration, and ion exchange are widely used *ex situ* treatment technologies for inorganics in groundwater and are discussed in the following paragraphs. *In situ* treatment technologies are used less frequently.

The combination of **precipitation/flocculation** and sedimentation is a well-established technology for removal of metals and radionuclides from groundwater. This technology pumps groundwater through extraction wells and then treats it to precipitate heavy metals. Typically, removal of metals involves precipitation with hydroxides, carbonates, or sulfides. Hydroxide precipitation with lime or sodium hydroxide is the most common choice. Generally, the precipitating agent is added to water in a rapid-mixing tank along with flocculating agents such as alum, lime, and/or various iron salts. This mixture then flows to a flocculation chamber that agglomerates particles, which are then separated from the liquid phase in a sedimentation chamber. Other physical processes, such as filtration, may follow.

Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium. Pressure-differentiated filtration techniques include separation by centrifugal force, vacuum, or positive pressure. The chemicals are not destroyed; they are merely concentrated, making reclamation possible. Parallel installation of double filters is recommended so groundwater extraction or injection pumps do not have to stop operating when filters backwash.

Ion exchange is a process whereby the toxic ions are removed from the aqueous phase in an exchange with relatively innocuous ions (e.g., sodium chloride) held by the ion exchange material. Modern ion exchange resins consist of synthetic organic materials containing ionic functional groups to which exchangeable ions are attached. These synthetic resins are structurally stable and exhibit a high exchange capacity. They can be tailored to show selectivity toward specific ions. The exchange reaction is reversible and concentration-dependent; the exchange resins are regenerable for reuse. The regeneration step creates a wastestream that must be treated separately. All metallic elements present as soluble species can be removed by ion exchange. A practical influent upper concentration limit for ion exchange is about 2,000 mg/L. A higher concentration results in rapid exhaustion of the resin and high regeneration costs.

Technologies for Treating Contaminated Soils

Volatile Organic Compounds and Fuels

Common treatment technologies for VOCs in soil, sediment, and sludge include biodegradation, incineration, and excavation with offsite disposal.

Biodegradation uses a process in which indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) degrade (i.e., metabolize) organic contaminants found in soil and/or groundwater. In the presence of sufficient oxygen (aerobic conditions), microorganisms ultimately will convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the contaminants ultimately will be metabolized to methane and carbon dioxide. Sometimes contaminants may not be completely degraded, but instead be transformed to intermediate products that may be less hazardous than, equally as hazardous as, or more hazardous than the original contaminant.

All types of biodegradation, both *in situ* and *ex situ*, can be evaluated for use in soil remediation: *in situ* bioremediation, bioventing, composting, controlled solid phase, or landfarming. Treatability studies should be conducted to optimize design parameters, such as degradation rates, supplemental organism addition, cleanup levels achievable, degradation intermediates, and nutrient/oxygen addition.

The *in situ* bioremediation of soil typically involves the percolation or injection of groundwater or uncontaminated water mixed with nutrients. *Ex situ* bioremediation typically uses tilling or continuously mixed slurries to apply oxygen and nutrients, and is performed in a prepared bed (liners and aeration) or reactor.

Incineration uses high temperatures, 870 to 1,200 ^{o}C (1,400 to 2,200 ^{o}F), to volatilize and combust (in the presence of oxygen) organic constituents in hazardous wastes. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99 percent requirement for hazardous waste and can be increased to meet the 99.9999 percent requirement for polychlorinated biphenyls (PCBs) and dioxins. Distinct incinerator designs available for solids are rotary kiln, fluidized bed, and infrared units.

Excavation and removal of contaminated soil (with or without stabilization) to a landfill have been performed extensively at many sites. **Landfilling** of hazardous materials, especially hazardous wastes, is becoming increasingly difficult as a result of growing regulatory control, and may be cost-prohibitive for sites with large volumes, greater depths, or complex hydrogeologic environments. Determining the feasibility of offsite disposal requires knowledge of land disposal restrictions and other regulations developed by State governments.

Soil vapor extraction (SVE) is an *in situ* unsaturated (vadose) zone technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semivolatile contaminants from the soil. The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and State air discharge regulations. Explosion-proof equipment should be used for fuels. Vertical extraction vents are typically used at depths of 1.5 meters (5 feet) or greater and have been successfully applied as deep as 91 meters (300 feet). Horizontal extraction vents (installed in trenches or horizontal borings) can be used as warranted by contamination zone geometry, drill rig access, or other site-specific factors.

Groundwater extraction pumps may be used to reduce groundwater upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection may be effective for facilitating extraction of deep contamination, contamination in low-permeability soils, and contamination in the saturated zone.

Low-temperature thermal desorption (LTTD) systems are physical separation processes and are not designed to destroy organic chemicals. Wastes are heated to between 90 ^{o} and 315 ^{o}C (200 ^{o} to 600 ^{o}F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. Groundwater treatment concentrates the collected contaminants (e.g., carbon adsorption or condensation). The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them. Decontaminated soil retains its physical properties and ability to support biological activity.

Inorganic Chemicals

The most commonly used treatment technologies for inorganics in soil include solidification/stabilization (S/S), and excavation and offsite (landfill) disposal. Solidification/stabilization is described briefly below; excavation and landfill disposal has already been discussed.

Solidification processes produce monolithic blocks of waste with high structural integrity. The contaminants do not necessarily interact chemically with the solidification reagents (typically cement/ash) but are mechanically locked within the solidified matrix. Stabilization methods usually involve the addition of materials such as fly ash, which limit the solubility or mobility of waste constituents, even though the physical handling characteristics of the waste may not be changed or improved. Solidification/stabilization of contaminated soil can be conducted either *in situ* or *ex situ*.

Technologies for Decontamination and Decommissioning of Buildings

Decontamination

Decontamination is a major decommissioning activity that may be used to accomplish several goals, such as reducing occupational exposure, reducing the potential for the release and uptake of radioactive material, permitting the reuse of a component, and facilitating waste management.

There are two primary categories of decontamination equipment or techniques: chemical and mechanical. Chemical decontamination uses concentrated or dilute solvents in contact with the contaminated item to dissolve either the base metal or the contamination film covering the base metal. Dissolution of the film is intended to be nondestructive to the base metal and is generally used for operating facilities. Dissolution of the base metal should be considered only in a decommissioning program where the item will never be reused. Chemical flushing is recommended for remote decontamination of intact piping systems. Chemical decontamination has also proven to be effective in reducing the radioactivity of large surface areas such as floors and walls as an alternative to partial or complete removal.

Mechanical and manual decontamination employs physical techniques. More recently, mechanical decontamination has included washing, swabbing, using foaming agents, and applying latex-peelable coatings. Mechanical techniques may also include wet or dry abrasive blasting, grinding of surfaces, and removal of concrete by spalling. These techniques are most applicable to the decontamination of structural surfaces.

In recent years, many innovative decontamination techniques have been proposed. For the most part, these emerging technologies are hybrid technologies comprising one or more of the following methods: chemical, electrochemical, biological, mechanical, or sonic methodology.

Dismantling, Segmenting, and Demolition

The decommissioning of nuclear facilities largely involves the segmentation of metal components and the cutting and demolition of concrete structures. Various techniques have been used for segmenting and demolishing these components and structures, and new techniques are being developed continually. The dismantling/segmenting techniques may be grouped into three categories: mechanical (e.g., saws, shears, cutters, explosives), thermal (e.g., plasma arc, oxygen burning, flame cutting), and others (e.g., abrasive water jet, carbon dioxide blasting).

Mechanical cutting techniques use mechanical forces and/or motions to cut various components (e.g., structures, piping) that may be encountered during decommissioning. The mechanical motions (reciprocating, circular) and forces (shear) are usually driven electrically, pneumatically, or hydraulically, resulting in the cutting and/or breaking of the component.

There are two types of thermal cutters: flame producers and arc producers. The more common are the flame-producing techniques where a flame is established by igniting fuel gases. With arc-producing techniques, an electrical arc is established between the tool and the workpiece. In both methods the workpiece is literally melted away.

Environmental Remediation Technologies—Case Studies

To date, the only serious review of operating remediation technologies from the standpoint of safety and health has provided cause for alarm. In September 1993, the Occupational Safety and Health Administration (OSHA) reported its findings based on inspections conducted at the following Superfund incinerator sites, most of which are similar in setup, as shown in Figure 1:

- Old Midland Products in Ola, AR
- Rose Township in Oakland County, MI
- Sikes disposal pits in Crosby, TX
- Big D campground in Kingsville, OH
- Bridgeport Rental and Oil Services in Bridgeport, NJ

OSHA found numerous safety and health deficiencies, including inadequate procedures for Process Safety Management (PSM) and for responding to an emergency. OSHA recommends as a best management practice that PSM be used even though the standard may not specifically apply. The adequacy of the agency's own response mechanisms was called into question in one case, where an inspection of an incinerator indicated that there were no standard operating procedures (SOPs) for emergency shutdown of the unit. The operator of the incinerator received a citation as a consequence, but it was unclear what would constitute a situation serious enough to require the unit to shut down, and how that would be done efficiently.

In addition to the specific safety hazards documented at the incinerator sites, epidemiological studies indicate the presence of general health hazards at such sites. A Swedish study of 176 male workers employed for at least 1 year at a municipal waste incinerator found excess deaths from lung cancer and ischemic heart disease.[2]

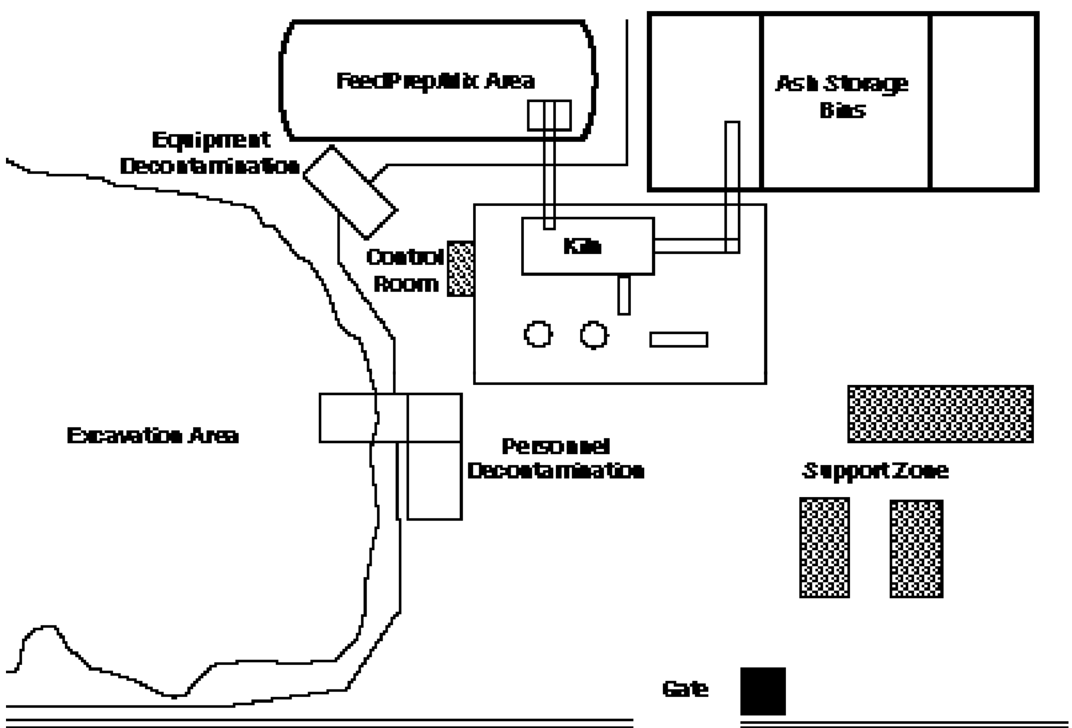


Figure 1. Generic incinerator.

[2] P. Gustavsson. "Mortality among Workers at a Municipal Waste Incinerator," *American Journal of Industrial Medicine*, 15:245-253, 1989.

Investigation and Identification of Hazards

It has been estimated that in some cases as much as 40 percent of the cost of remediation has been spent on controlling associated safety and health hazards through procedures, equipment, and training. Despite the large investment, safety and health procedures often are not considered at the outset during the development of new remediation technologies. Safety and health experts should be consulted routinely during the design phase to identify and investigate safety and health hazards.

Figure 2 illustrates a process for identifying hazards. Figure 3 shows the use of a site health and safety plan (HASP) as the medium through which hazards can be minimized. Specific health and safety hazards must be addressed through the HASP as well as the program requirements of the Hazardous Waste Operations and Emergency Response (HAZWOPER) Standard (see 29 CFR 1910.120).

The result of this effort is the development of component programs that address particular hazards identified through the analysis. Safety and health professionals familiar with a given site can use these component programs as guidance in developing a site-specific program.

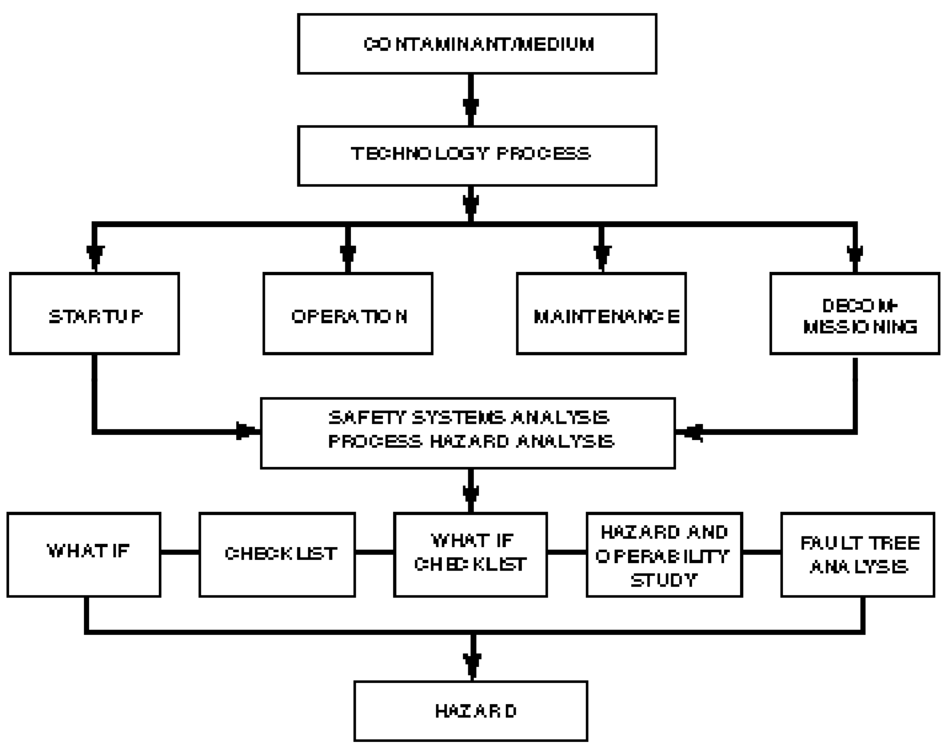


Figure 2. Technology hazard identification process.

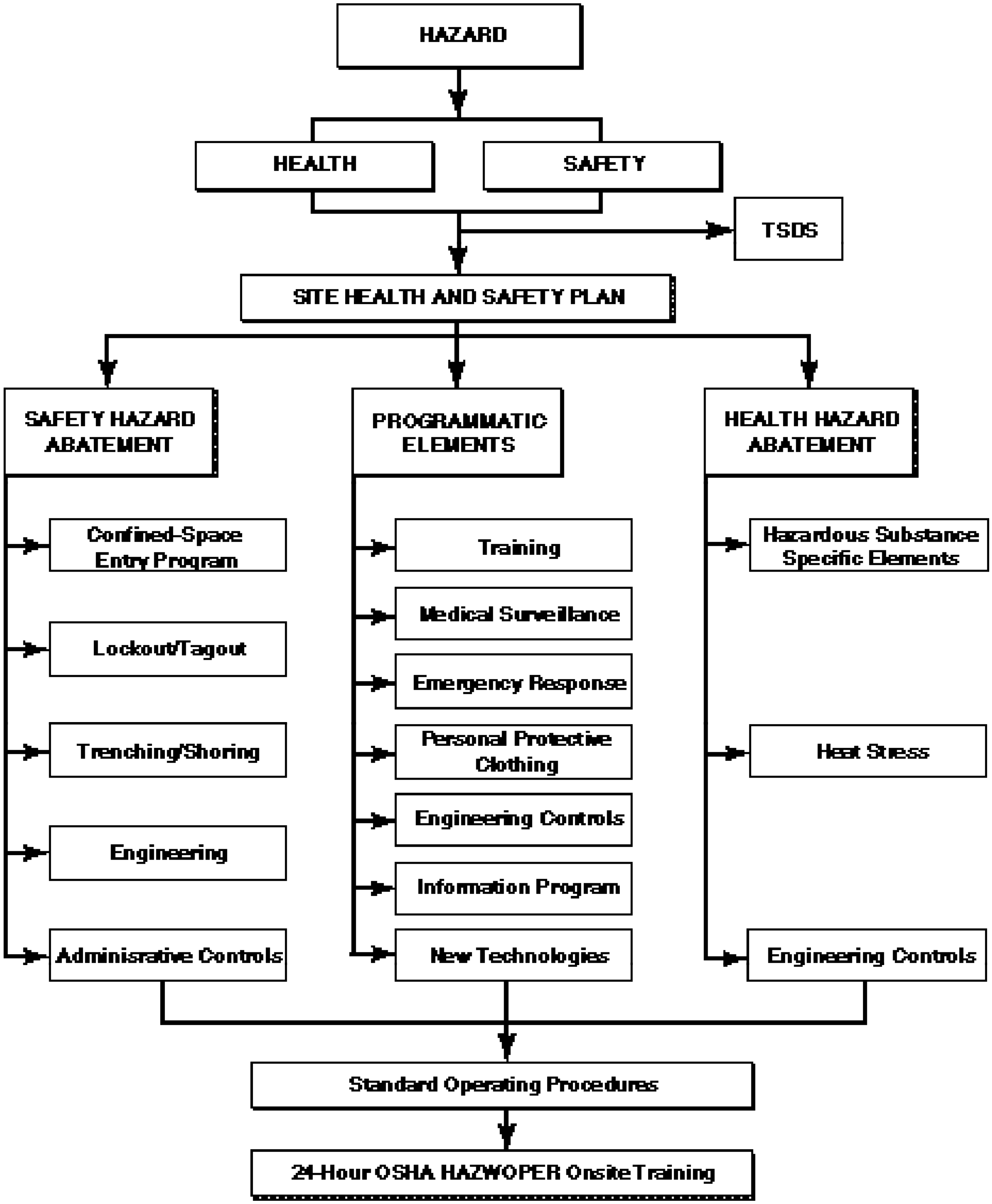


Figure 3. Technology hazard mitigation process.

Checklists for Safe Transitions

The transition from one phase of technology implementation to another can be extremely hazardous, such as when a technology moves from construction through startup to operation, or from operation through shutdown to maintenance, or as the result of decommissioning operations. A transition may be the result of an emergency in which the technology involved moves out of operation into shutdown mode. Because such transitions usually are inherently dangerous, SOPs should be developed to minimize potential consequences. These checklists are designed to remind operators of all the procedures required to move a technology safely from one phase of operation to another.

A Two-Part Approach to Addressing New Technology Hazards

In attempting to transition from general considerations of worker safety and health associated with new technologies, as presented in the preceding text, the Workshop participants sought to develop guidance approaches to addressing the hazards associated with the design, development, deployment, use, and unique emergency hazards specific to new technologies. Toward that objective, the Workshop participants focused attention on the development of two guidance documents:

I. Applying Process Safety Management Techniques and Technology Safety Data Sheets to the Development of New Cleanup Technologies.

II. Emergency Response Considerations for New Technology.

These two guidance documents are presented in the following as Parts I and II.